Goosebumps: Towards Sensory Substitution Using Servo Motors

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Abstract
Goosebumps is a wearable device that enables users to get spatial information using haptic feedback through servo motors. By rotating the motors, spatial information on a single axis can be encoded and processed by the users in real time. In this demonstration, the participants will be trained to use the system to use a simple driving game similar to Out Run [1] while being blindfolded. Our system thus provides sensory substitution, where visual information (such as car position and road orientation) will be encoded with haptic information. Goosebumps has multiple applications, from Virtual Reality to visually impaired people. This demo, in a reduced form, has been presented previously at the 2016 HacknRoll competition, where it was presented with the first prize.

Author Keywords
Haptic feedback; servo motors; sensory substitution; eyes-free;.

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces – Haptic I/O.

Introduction
A fundamental hurdle for Virtual Reality systems is the attempt to communicate all sensory aspects of a virtual

Figure 1. Javascript Racer (v4), used for the demonstration, is based on Out Run [1].

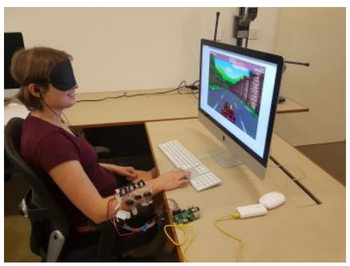

Figure 2. Setup of the experiment.

world to a user so that he or she 'feels' present in it. The audio-visual aspect of the world is the one that has made the most progress in recent years. However, there is significant value in providing additional sensory input to the user, either as a method of increasing the amount of data being conveyed about the virtual world - important in scenarios such as drone operation or MMORPG gaming where users need high bandwidth information about their presence in the world - or as a pathway towards providing a more holistic and immersive virtual experience.

Non-invasive methods of augmenting sensory input to the human brain have shown that the neural pathways that interpret the world are quite malleable [2]. In the framework proposed by Bach-y-Rita et al. [2], mild electric shocks administered to the tongue enabled users - both sighted and blind - to 'see' using their tongues and to perform complex tasks such as identifying text and catching a ball thrown at them. Provided with appropriately formatted input, the brain is able to 'grow' a new sense out of an existing one.

For this project, we decided to use inexpensive servo motors as they can provide rich (continuous) feedback. Compared to vibrotactile feedback, motors can offer permanent feedback, i.e. the motor is stuck at a given position. Using a protocol that optimizes the information transmitted to the brain as well as methods that prevent sensory decay, we are able to enable the brain to recognize and feel a new sense using haptic feedback. Here we describe the technical implementation as well as the primary challenges encountered.

Sensory Resolution

Hardware and Software

The experimental setup consists of a 3×3 grid of micro-servos that can provide up to 246 milli-Nm of force, arranged on a flexible plastic film wrapped around the user's arm. The servos are outfitted with 3 cm arms that rotate down to push lightly into the user's skin, connected to a Raspberry Pi Model B, running a python server communicating with the game server.

The driving game is rendered using client-side JavaScript, and the position of the car is communicated to the Raspberry Pi through http over Wi-Fi. The server in the Raspberry Pi converts these into time-variant signals that are then fed to the servos using Pulse-Width Modulation.

Procedure

The user is given a short period of time to play the game using keyboard controls with Goosebumps attached, with sole instructions to avoid trees and cars and to complete fast laps of the racetrack. Following this period, the user is blindfolded and asked to continue gameplay (Figure 2).

Protocol

The transmission protocol used the servos positioned at the four corners as independent channels communicating speed, rate of turn, obstruction, etc. The servos in between blend the input, providing a constantly varying frequency by alternating between their neighbors. Each servo was continuously activated at frequencies ranging from 2-10 Hz, being altered by +-0.1-0.5 Hz at random at time intervals of two seconds if the input remained unchanged.

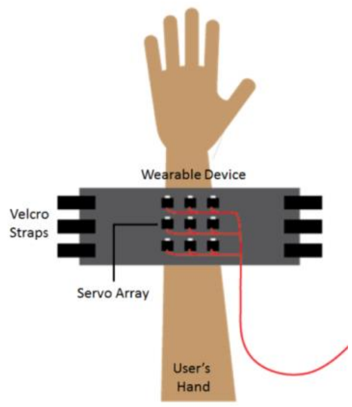

Figure 3. Servo Arrangement on the user's arm.

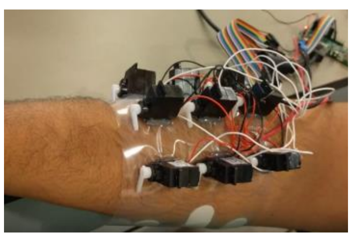

Figure 4. ServoStitutio deployed.

Sensory Resolution

The first challenge lies in the resolution of the sense being replaced, i.e. the theoretical maximum amount of information that can be conveyed to the brain. In true computing parlance, this can be split into the parallel and serial bandwidth of the sense. Senses such as sight possess high parallel bandwidth - the human eye is able to process up to many megapixels of information at the same time - whereas others like hearing are detect shifts in tone and frequency as information. In the work by Bach-y-Rita et al. [2], an 8×8 matrix with varying frequencies was used to convey visual information.

Here we make use of a 3×3 grid spread out across 10 square centimeters (Figure 3), making use of distinct bands of frequency to convey information. For this work, we only used the four motors on the corners.

Information Encoding

Our device can potentially be used to encode complex information. As a preliminary testing, we decided to see whether it can be used to play a driving game while being blindfolded. We decided to use Javascript Racer (Figure 1), a game loosely based on Out Run. The goal of the game is to drive a car on one axis while avoiding obstacles and other cars. The car position can only vary on the X axis, and the game shows an overview of the upcoming road.

As such, we decided to encode both the current position of the car (compared to the center of the screen), as well as the orientation of the upcoming road. We use two motors per piece of information, with the motor producing "pokes" at varying frequencies. If the car is far on the left edge, the left motor (see Figure 3) will poke at high frequency. Similarly, if a huge left turn is coming, the left motor used for the upcoming road information will poke the skin at a high frequency.

Sensory Decay

Experiments with haptic feedback provided insight into optimizing the transmission of information to the brain. Using individual pokes as a feedback, with a given angle encoding an offset from the center, proved effective in the beginning, but experienced sensory decay as the brain learned to filter out the input as noise, similar to effects of clothes and apparel on skin. Vibrational feedback was especially susceptible to this form of decay, as the areas affected were rapidly numbed to the effects. Continuously varying frequencies of 'pokes' were found to be effective at fighting sensory decay. After a short training of 10 to 15 minutes, users are generally able to perceive information and interpret it correctly, making them able to play the game efficiently.

Any discomfort the users described in the early stages of this process - which proved minimal after the use of a warped surface between the servos and the skin - disappeared after this period. This formed the basis of the protocol for transmitting information.

Learning

The next challenge involved eliciting an intuitive response from the users rather than a conscious one. A fundamental difference in performance was observed between users when different protocols were applied pointing to a significant change in perception. When the users were presented with haptic patterns that were static in nature, they responded to the input by consciously remembering the patterns. This was an approach that did not scale when presented with complex real-time data that required quick responses, suggesting that the information had simply been remembered instead of learned. This was evident in their response to the game, where they performed consistently worse after the training period and required reminders of the patterns forgotten.

When presented with continuously varying patterns that had no beginning or end the users began by exploring the world using the senses they knew, becoming accustomed to the haptic feedback as they explored the world. At the end of the training period, they were able to continue with the sole input coming from Goosebumps without a conscious understanding of the input.

Summary Response

SensX – the first iteration of Goosebumps - was presented to the general public at a hackathon, where it proved quite popular, enabling us to test the system over a wide array of demographics. The primary observation here was that children under the age of 10 proved to need shorter training periods, which we suspect is due to increased neuroplasticity. All users were able to play the game after the training period without additional input, and general reactions were of enthusiasm and surprise after discovering they were doing well, leading to an internal competition which was unsurprisingly won by the two children present.

Conclusion

Goosebumps makes it possible to remap sensory input using specific protocols designed to reconfigure sensory perception in the brain. This allows for users to process complex, continuous data without conscious effort, allowing for applications that require additional input to be presented to the user without sensory overload.
A few specific applications include providing real time map information to combat units as well as players of First-Person Shooters, non-invasively returning lost senses such as sight and hearing, as well as providing extrasensory perception such as additional frequencies of hearing and sight.

Moving on, additional research could help optimize the protocol to transfer more information, using multiple devices working in tandem to convey extra dimensions of data as well as testing the limits of such augmentation.

References

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2. Bach-y-Rita. P. and Kercel, S. W. 2003. "Sensory substitution and the human- machine interface", Trends Cogn. Sci. 7 541–546. 10.1016/j.tics.2003.10.013.